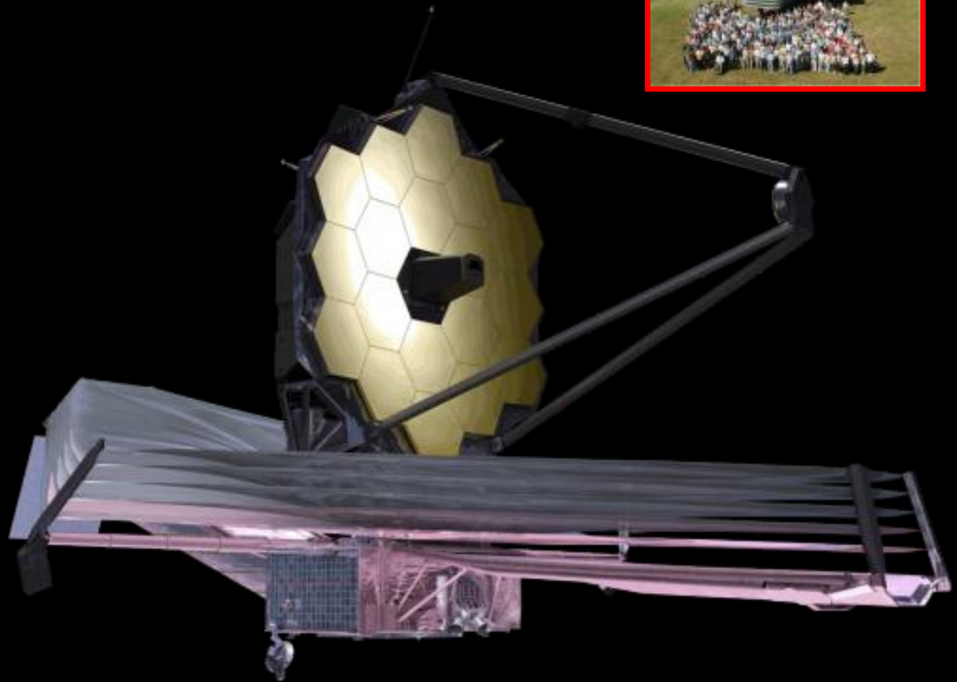
James Webb Space Telescope: Solar System Science and Mission Progress

John Mather
JWST Senior Project Scientist
NASA's Goddard Space Flight Center

on behalf of 7 billion current Earthlings, ~10,000 future observers, ~ 1000 engineers and technicians, ~ 100 scientists worldwide, 3 space agencies

James Webb Space Telescope



Organization

- Mission Lead: Goddard Space Flight Center
- Senior Project Scientist: John Mather
- International collaboration: ESA & CSA
- Prime Contractor: Northrop Grumman Aerospace Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) & Near IR Imaging Slitless Spectrometer – CSA
- Operations: Space Telescope Science Institute

Description

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission requirement (10-year propellant lifetime)

Planetary Scientists helping to define and build JWST

- Heidi Hammel, IDS (interdisciplinary scientist), AURA VP
- Jonathan Lunine, IDS, Cornell
- Stefanie Milam, GSFC project science team
- Mike Meyer, ETH Zurich, NIRCam team, was member of first SWG (along with Phil Nicholson of Cornell) advocating solar system science, wrote Design Reference Mission items

What's Special about JWST solar system capabilities?

- HST (or better) angular resolution at longer wavelengths: diffraction limited 6.5 telescope at 2 µm (resolve planets, satellites, comets…); smallest pixels 0.032 arcsec
- Zodi background limited imaging sensitivity for $\lambda < 12$ µm (faint objects like KBO's, asteroids, satellites of Pluto, planetary rings)
- Full coverage from 0.6 to 28 µm with imaging *and* spectroscopy, $R = \lambda/\delta\lambda = 3000$ (chemistry and physics)
- Follows ephemeris up to at least 0.03 arcsec/sec for moving targets, enough for all accessible solar system targets
- Can observe all planets and satellites except Mercury, Venus, Earth, and Moon (from 85 to 135 deg from Sun)
- Subarray readout modes for bright objects

The James Webb Space Telescope

James E. Webb (1906 – 1992)

- Second Administrator of NASA (1961 – 1968)
- Oversaw first & Second manned spaceflight programs (Mercury, Gemini)
- Oversaw Mariner and Pioneer planetary exploration programs
- Oversaw Apollo program: On time, On budget! (he asked for enough!)
- Supported space science at NASA and universities

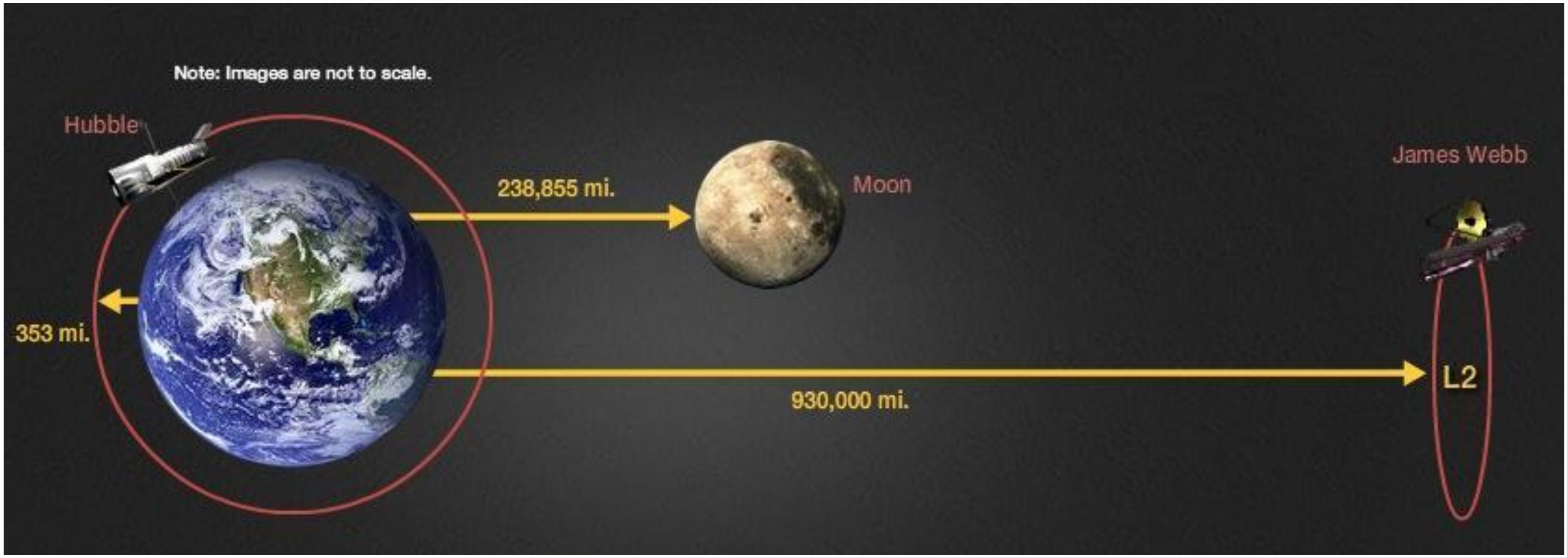
The James Webb Space Telescope

JWST Launch

- Launch vehicle is an Ariane 5 rocket, supplied by ESA
- Site will be the Arianespace's ELA-3 launch complex near Kourou, French Guiana

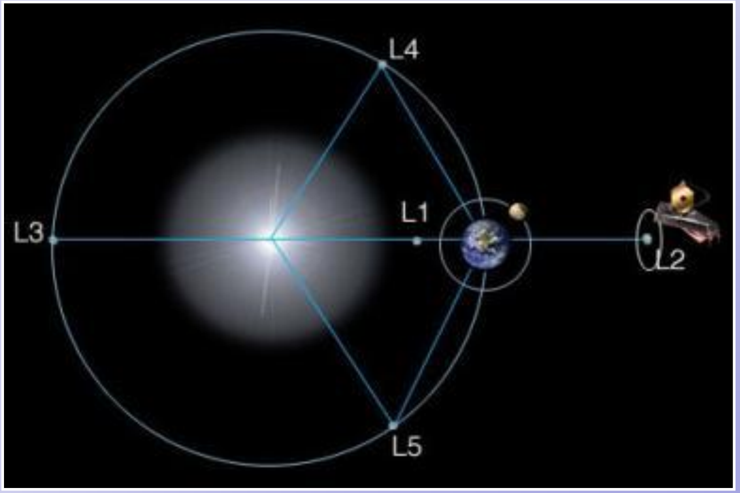
Arianespace – ESA - NASA

The James Webb Space Telescope



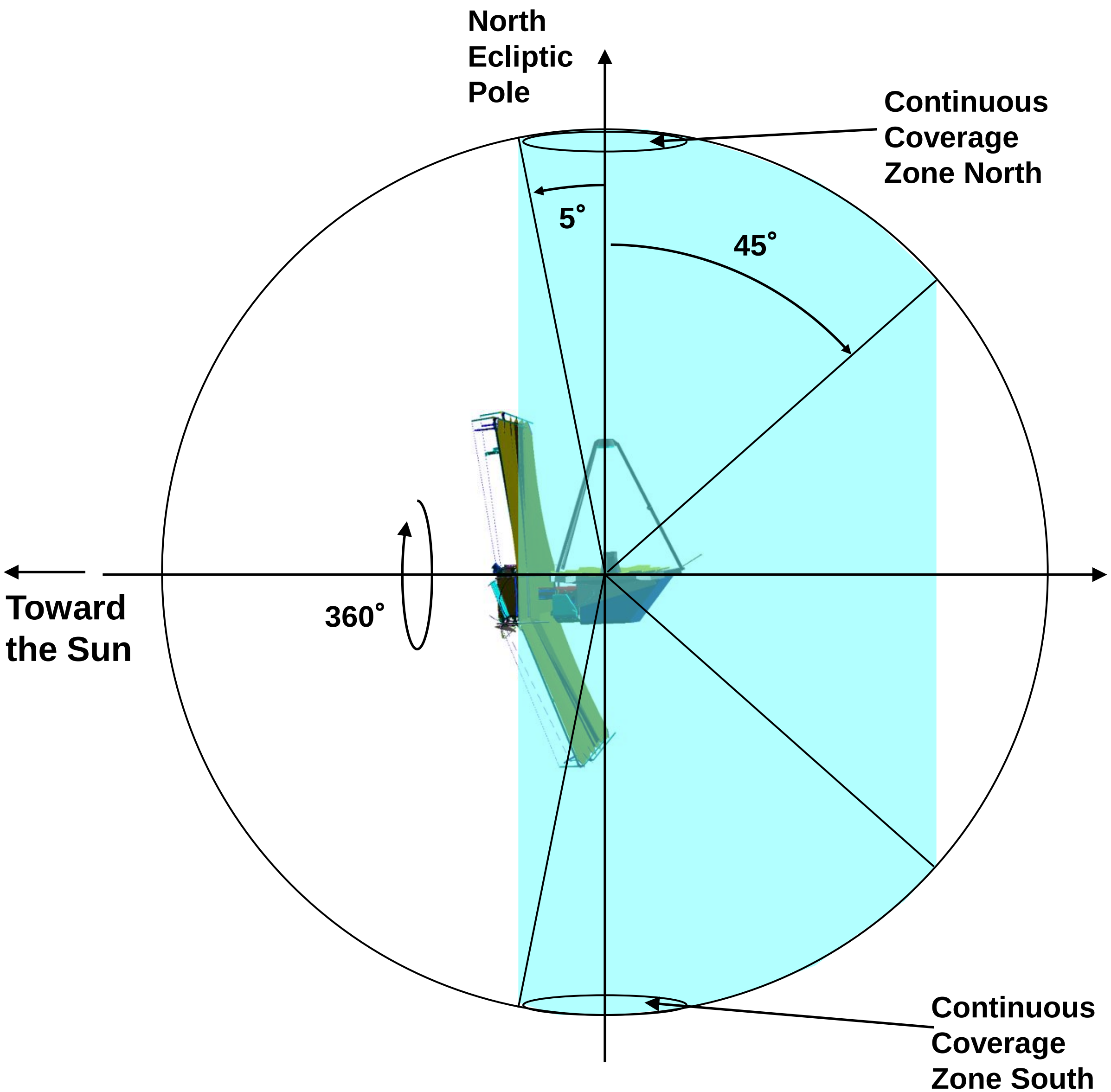
JWST Orbit

- JWST will orbit Sun-Earth L2 Lagrange point, 1.5 million km from Earth



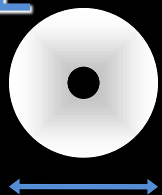
Observatory Design Field of Regard

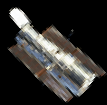
- The required celestial coverage for the observatory is 35% of the celestial sphere
- The sunshield is currently sized to provide at least 39% coverage
- Field of Regard is an annulus with rotational symmetry about the L2-Sun axis, 50° wide
- The observatory will have full sky coverage over a sidereal year
- There are continuous viewing zones 5° about the North and South Ecliptic Poles
- The observatory will have a roll capability about the telescope boresight of $\pm 5°$



JWST and its Precursors

HUBBLE

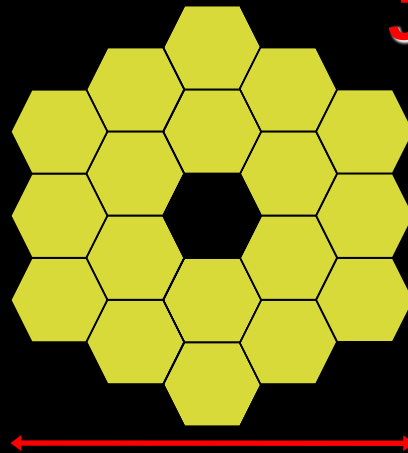




2.4-meter
T ~ 270 K

123” x 136”
$\lambda/D_{1.6\mu m}$~ 0.14”

JWST

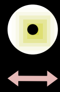


6.5-meter
T ~ 40 K

132” x 264”
$\lambda/D_{2\mu m}$~ 0.06”

114” x 84”
$\lambda/D_{20\mu m}$~ 0.64”

SPITZER

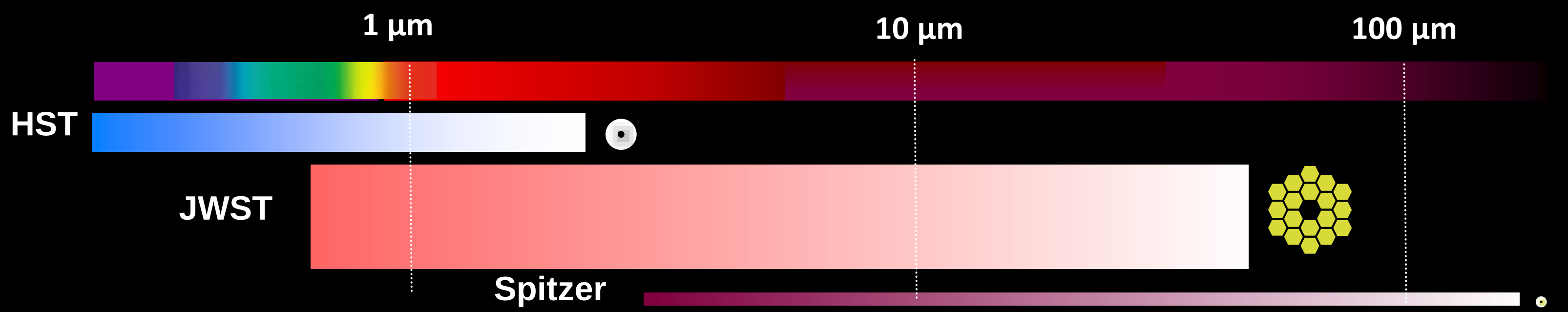


0.8-meter
T ~ 5.5 K

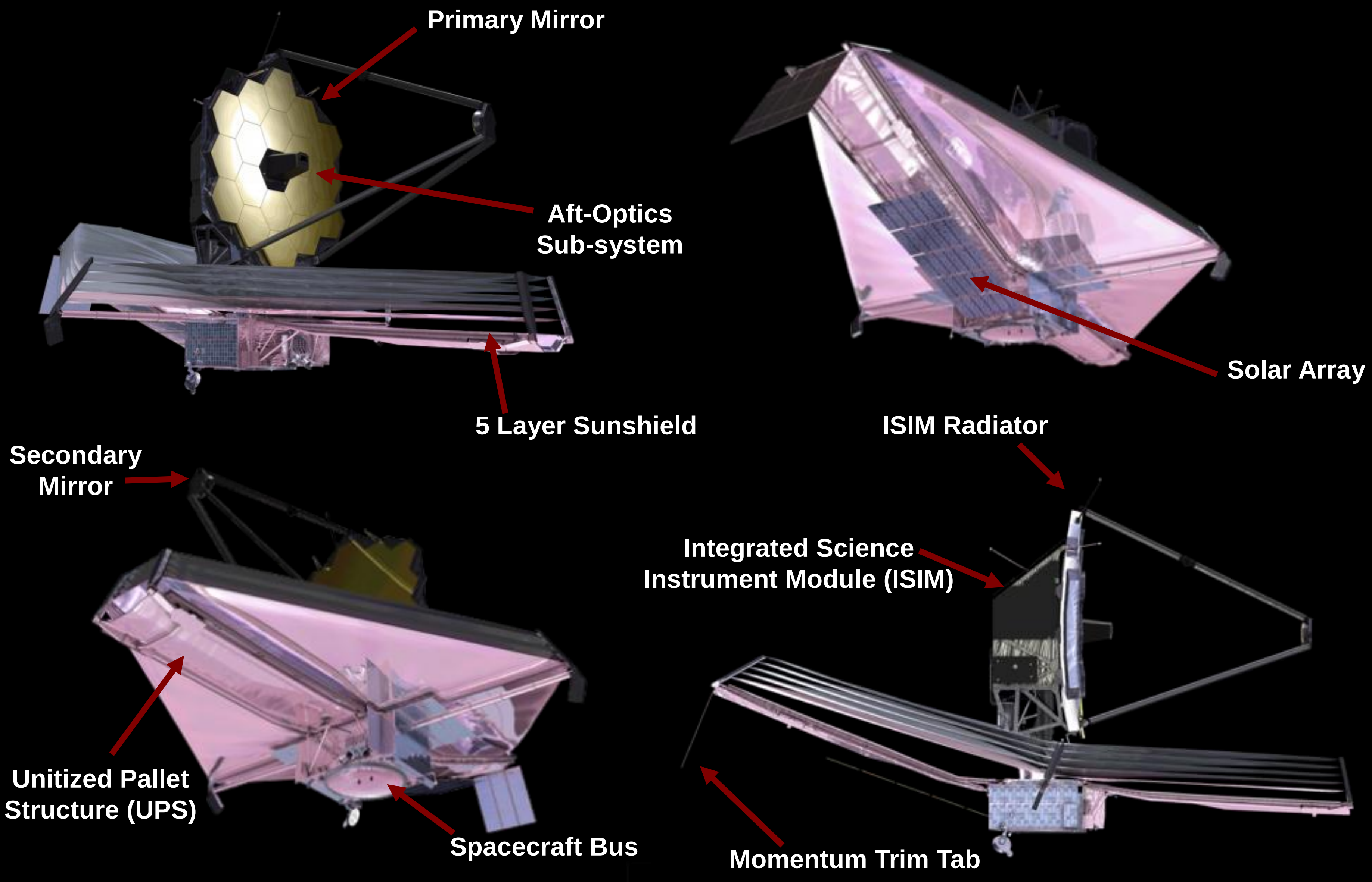
312” x 312”
$\lambda/D_{5.6\mu m}$~ 2.22”

324” x 324”
$\lambda/D_{24\mu m}$~ 6.2”

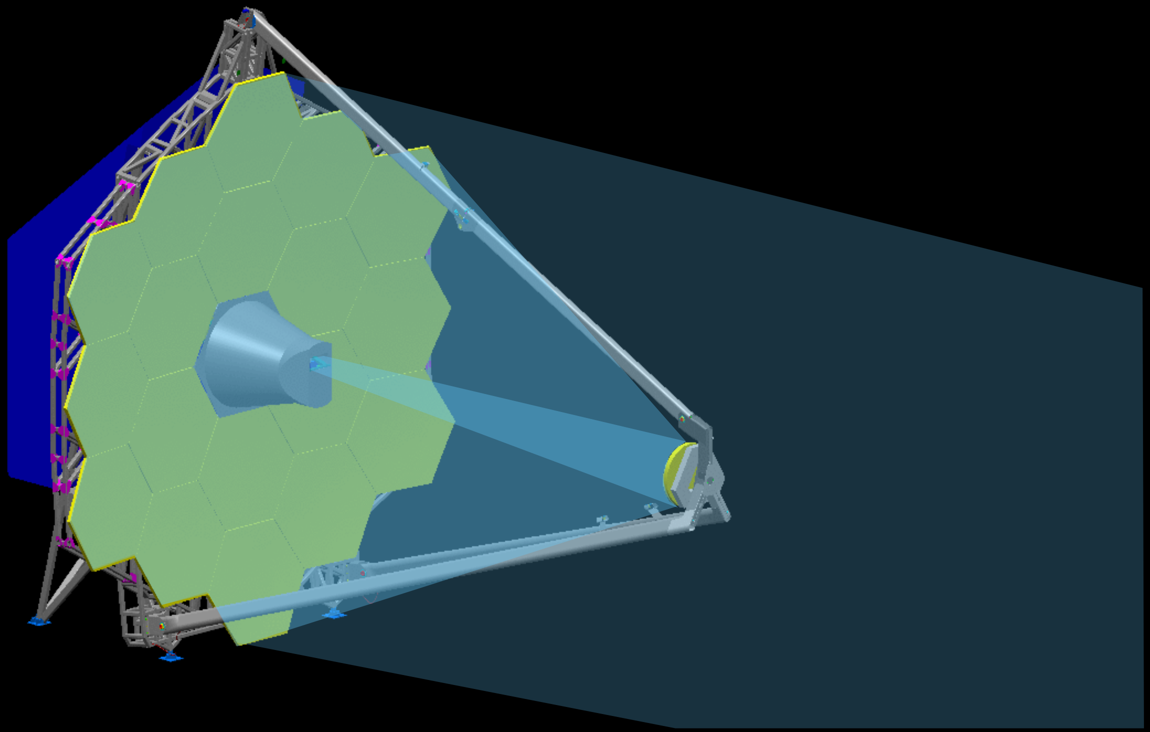
Wavelength Coverage



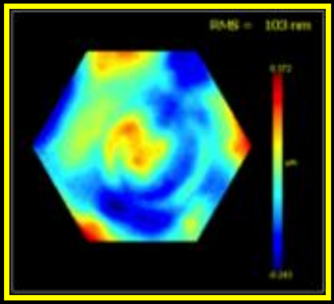
JWST Design: Key Features



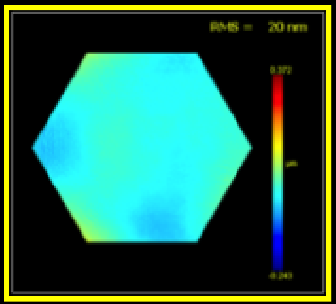
JWST's Telescope Design



- 18 primary mirror segments
- 6 degrees of freedom + ROC
- Beryllium mirrors
- 40 K operation
- <u>Cryo-polishing required</u>
- Long lead time fabrication



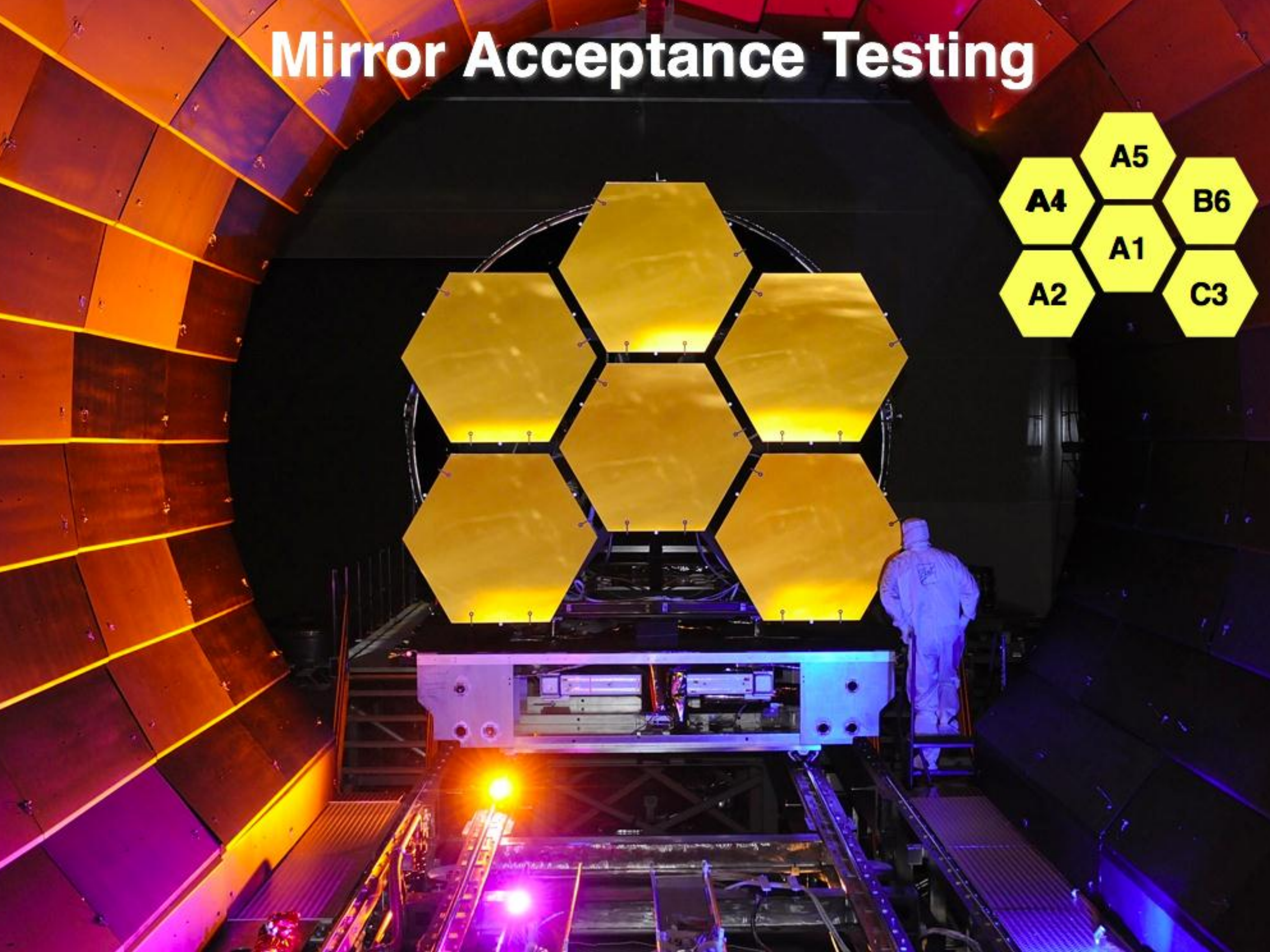
Ambient Surface



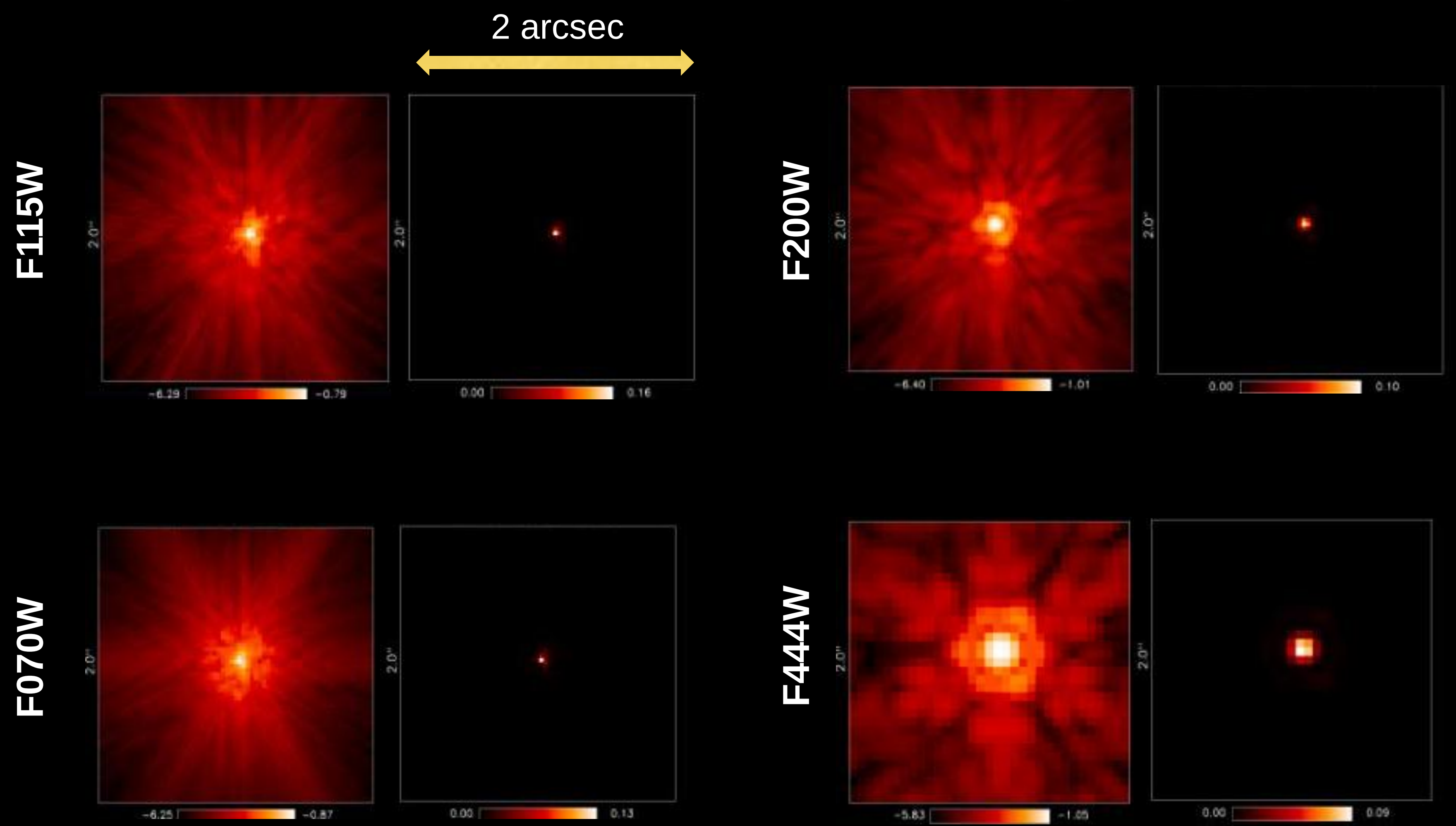
Cryo Surface

- *Elliptical* f/1.2 Primary Mirror (PM)
- *Hyperbolic* Secondary Mirror (SM)
- *Elliptical* Tertiary Mirror (TM) images pupil at *Flat* Fine Steering Mirror (FSM)
- Diffraction-limited imaging at ≥ 2 μm [150 nm WFE @ NIRCam focal plane]

Mirror Acceptance Testing

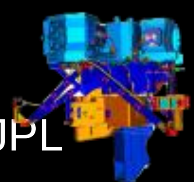
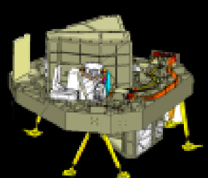


Predicted Image Quality: Diffraction Limited at 2 µm



Log Scale | Linear Scale | Log Scale | Linear Scale

JWST Instrumentation

Instrument	Science Requirement	Capability
NIRCam Univ. Az/LMATC 	Wide field, deep imaging ‣0.6 µm - 2.3 µm (SW) ‣2.4 µm - 5.0 µm (LW)	Two 2.2’ x 2.2’ SW Two 2.2’ x 2.2’ LW Coronagraph Dual filter wheel
NIRSpec ESA/Astrium 	Multi-object spectroscopy ‣0.6 µm - 5.0 µm	9.7 Sq arcmin Ω + IFU + slits 100 selectable targets: MSA R=100, 1000, 3000
MIRI ESA/UKATC/JPL 	Mid-infrared imaging ‣ 5 µm - 27 µm Mid-infrared spectroscopy ‣ 4.9 µm - 28.8 µm	1.9’ x1.4’ with coronagraph Filter wheel 3.7”x3.7” – 7.1”x7.7” IFU R=3000 - 2250
FGS/NIRISS CSA 	Fine Guidance Sensor 0.8 µm - 5.0 µm Near IR Imaging Slitless Spectrometer, ‣1.6 µm - 4.9 µm	Two 2.3’ x 2.3’ 2.2’ x 2.2’ R=150, 700 with coronagraph

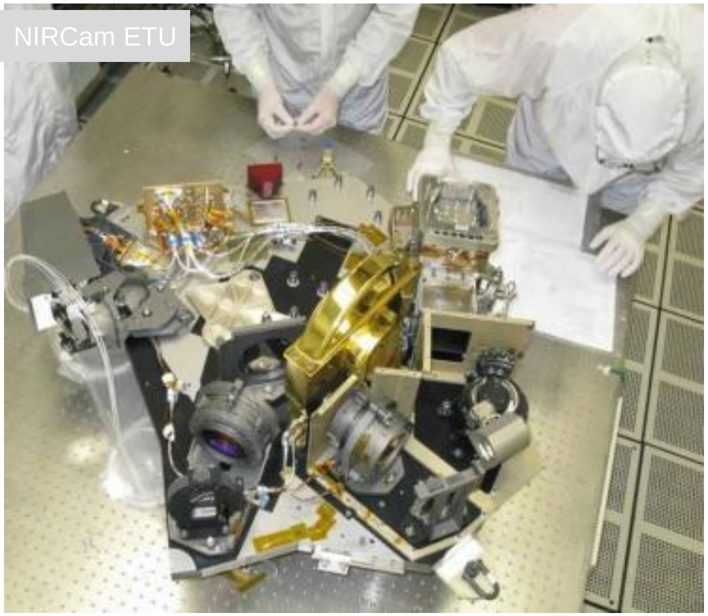
JWST **Imaging** Modes

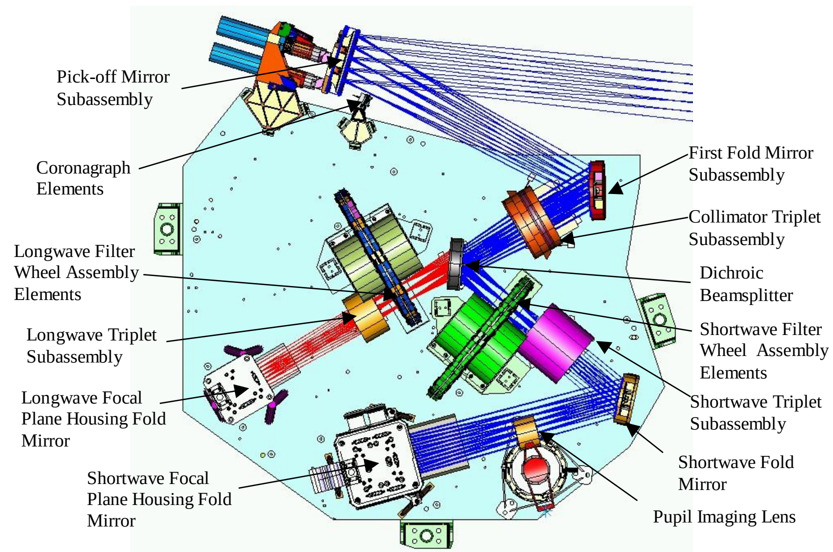
Mode	Instrumen t	Wavelength (microns)	Pixel Scale (arcsec)	Field of View
Imaging	NIRCam	0.6 – 2.3	0.032	2.2 x 2.2’
	NIRCam	2.4 – 5.0	0.065	2.2 x 2.2’
	NIRISS	0.9 – 5.0	0.065	2.2 x 2.2’
	MIRI	5.0 – 28	0.11	1.23 x 1.88’
Aperture Mask Interferometry	NIRISS	3.8 – 4.8	0.065	------
Coronography	NIRCam	0.6 – 2.3	0.032	20 x 20”
	NIRCam	2.4 – 5.0	0.065	20 x 20”
	MIRI	10.65	0.11	24 x 24”
	MIRI	11.4	0.11	24 x 24”
	MIRI	15.5	0.11	24 x 24”
	MIRI	23	0.11	30 x 30”

JWST **Spectroscopy** Modes

Mode	Instrument	Wavelength (microns)	Resolution ($\lambda/\Delta\lambda$)	Field of View
Slitless Spectroscopy	NIRISS	1.0 – 2.5	150	2.2 x 2.2’
	NIRISS	0.6 – 2.5	700	single object
	NIRCam	2.4 – 5.0	2000	2.2 x 2.2’
Multi-Object Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.4 x 3.4’ with 250k 0.2 x 0.5” microshutters
Single Slit Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	slits with 0.4 x 3.8” 0.2 x 3.3” 1.6 x 1.6“
	MIRI	5.0 – ~14.0	~100 at 7.5 microns	0.6 x 5.5” slit
IFU Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.0 x 3.0”
	MIRI	5.0 – 7.7	3500	3.0 x 3.9”
	MIRI	7.7 – 11.9	2800	3.5 x 4.4”
	MIRI	11.9 – 18.3	2700	5.2 x 6.2”
	MIRI	18.3 – 28.8	2200	6.7 x 7.7”

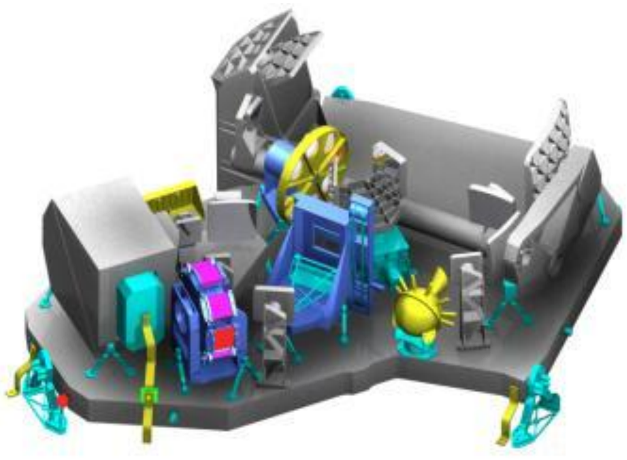
NIRCam will provide the deepest near-infrared images ever and will identify primeval galaxy targets for the NIRSpec

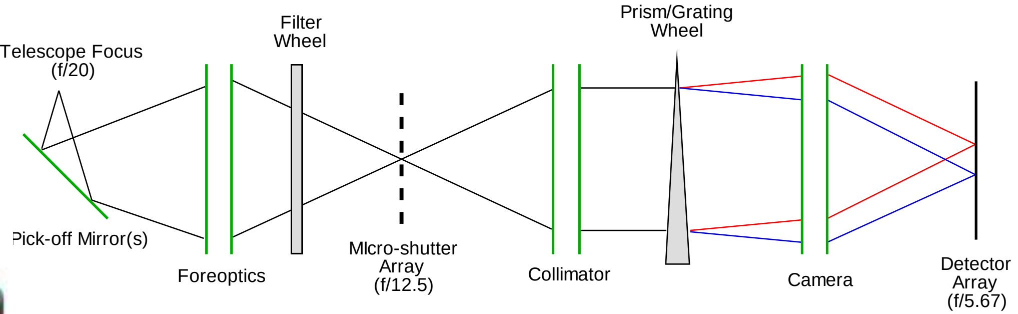


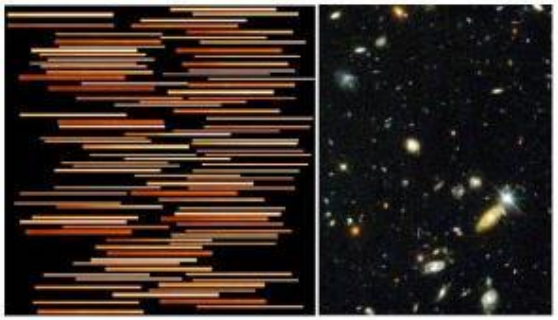


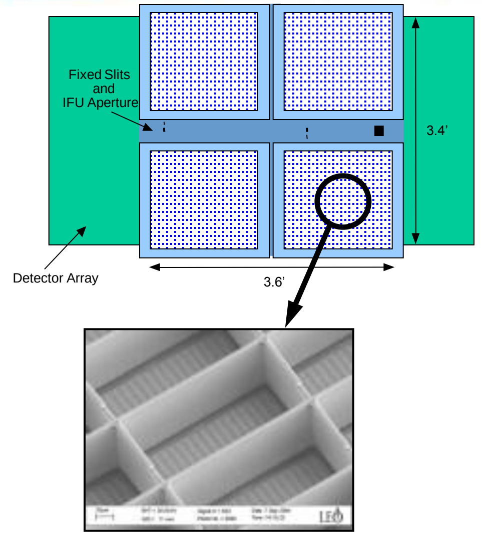
- Developed by the University of Arizona with Lockheed Martin ATC
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 4, 10, 100 (filters + grism), coronagraph
  - Field of view: 2.2 x 4.4 arc minutes
  - Angular resolution (1 pixel): 32 mas < 2.3 microns, 65 mas > 2.4 microns, coronagraph
  - Detector type: HgCdTe, 2048 x 2048 pixel format, 10 detectors, 40 K passive cooling
  - Refractive optics, Beryllium structure
- Supports OTE wavefront sensing

The NIRSpec will acquire spectra of up to 100 galaxies in a single exposure





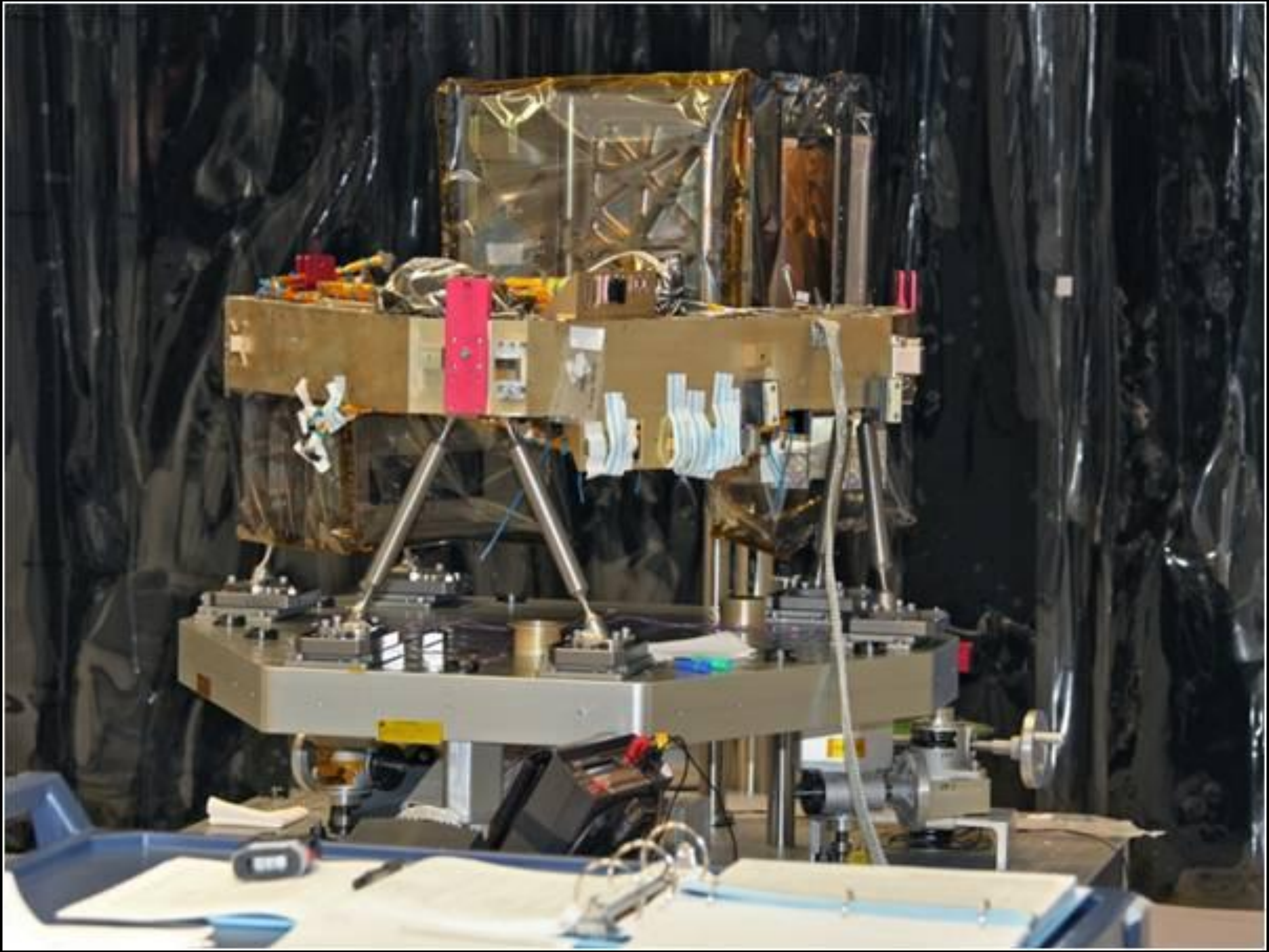




- Developed by the European Space Technology Center (ESTEC) with Astrium GmbH and Goddard Space Flight Ctr
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 100, 1000, 3000
  - Field of view: 3.4 x 3.4 arc minutes
    - Aperture control:
      - **Programmable micro-shutters**, 250,000 pixels
      - **Fixed long slits & transit spectroscopy aperture**
      - **Image slicer** (IFU) 3x3 arc sec
  - Detector type: HgCdTe, 2048 x 2048 format, 2 detectors, 37 K passive cooling
  - Reflective optics, SiC structure and optics

MIRI flies British Airways to USA

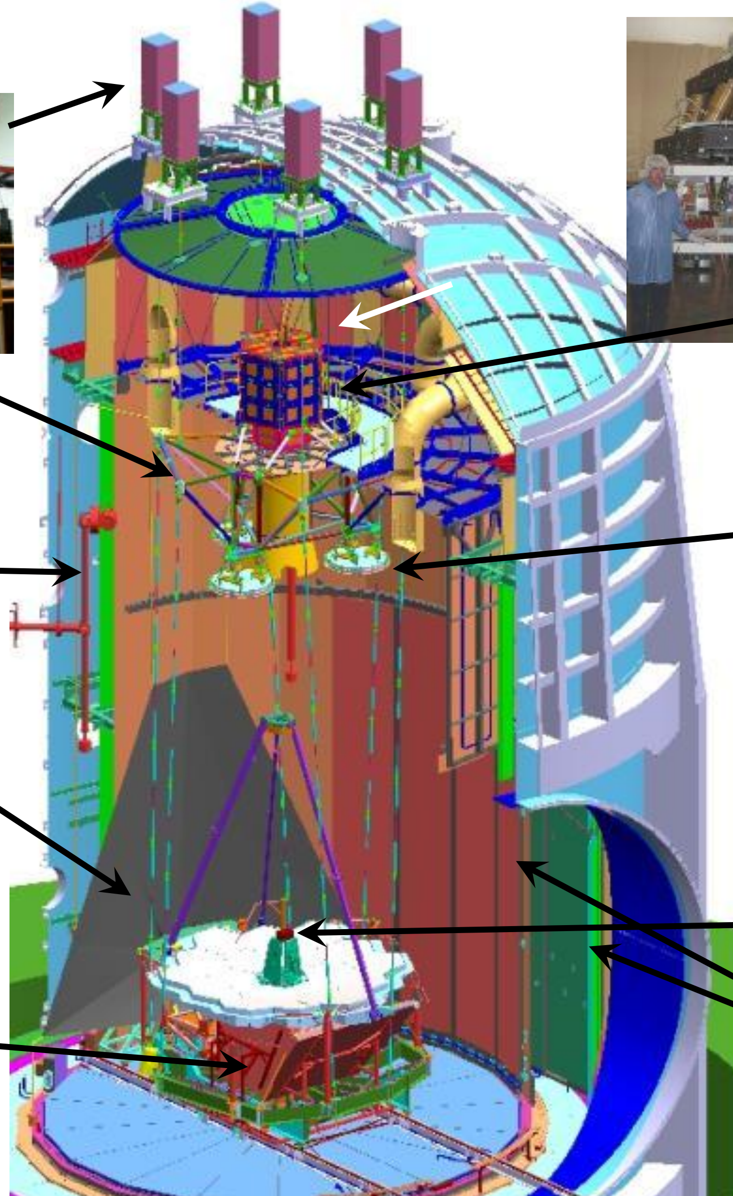
Flight Fine Guidance Sensor



Ambient Optical Alignment Stand for OTE & OTIS assembly recently installed in the SSDIF clean room

JSC Telescope Test for cold focus, thermal design

Chamber Isolation
1st unit tested

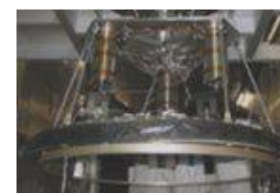


Center of Curvature
Optical Assembly
(COCOA)
Well into its I&T

Suspension
Subsystem

Photogrammetry
Windmills

3 Autocollimating Flat Mirrors
1st unit complete.
Units 2 & 3 polished



Space Vehicle Thermal
Simulator (SVTS) w/
cryo-cooler and
electronics

AOS Source Plate

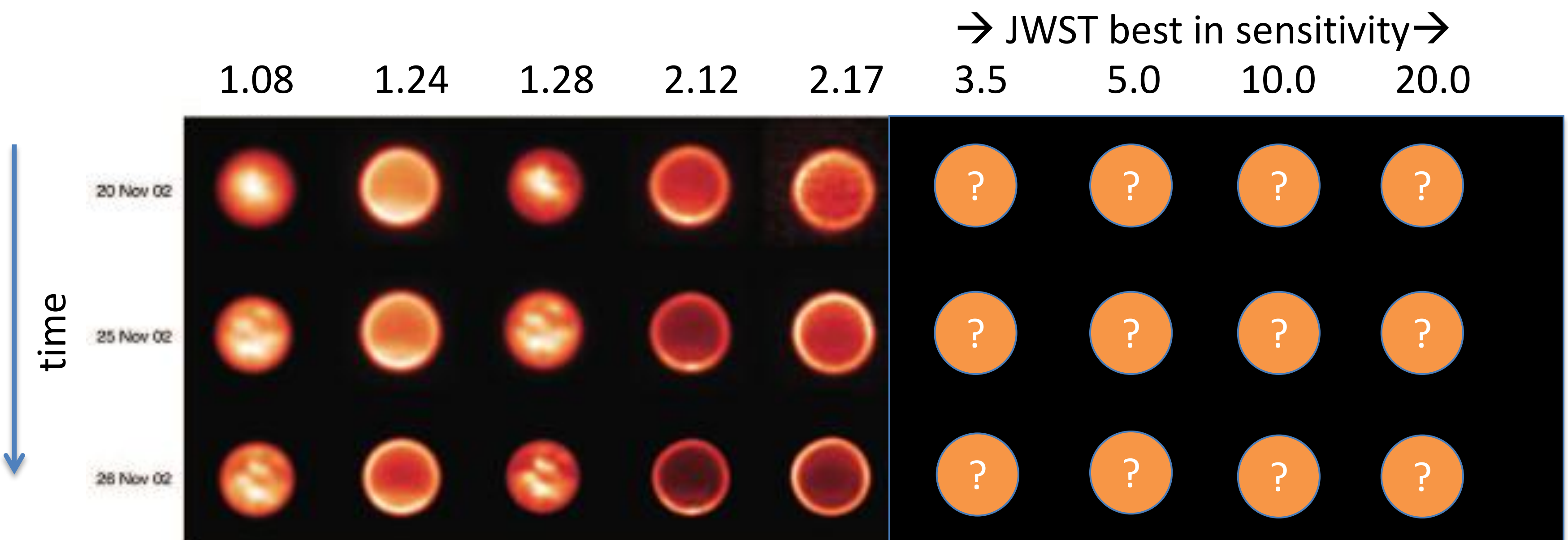
Hardpoint Offloader
Support System

LN2 and Helium
Cryogenic Shrouds
and “barn door”

The many faces of Titan

Saturn's moon Titan, second largest moon in the solar system, has a nitrogen-methane atmosphere four times denser at its surface than the air at sea level on Earth. In the cold environment methane forms clouds and rain, functioning in much the same way that water does in the Earth's atmosphere. The methane carves out river valleys and fills lakes and seas, discovered by Cassini.

•Because of the dense atmosphere, different wavelengths probe different altitudes, as shown in the series of images from the ESO's VLT. But JWST will cover a much longer, continuous wavelength range than Earth observatories, allowing a more complete top-to-bottom monitoring of Titan's atmosphere.

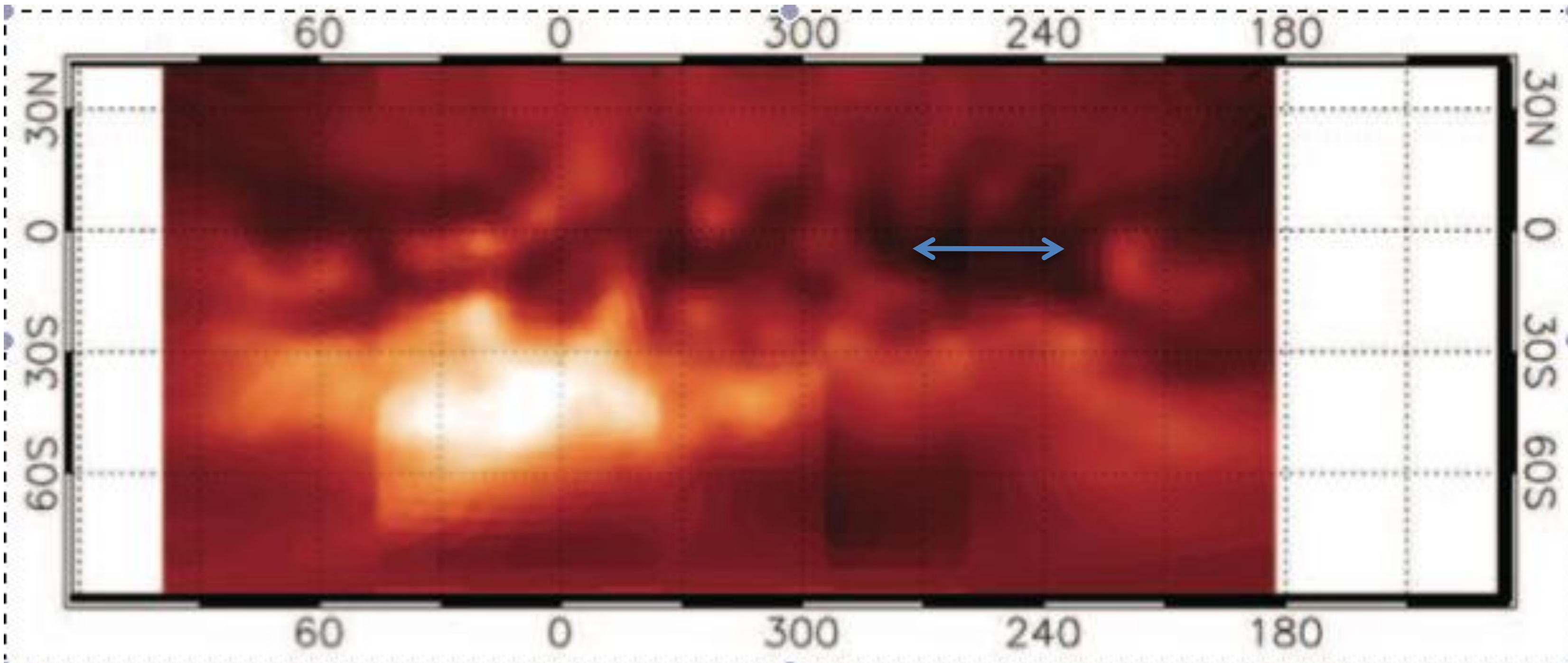


Left panel ©European Southern Observatory

Keeping tabs on large-scale changes on Titan after Cassini is gone

Cassini and ground-based telescopes have observed large scale changes in Titan's atmosphere and surface. In 2010, following an outburst of clouds, an area of the surface 2000 km in length darkened and then brightened again over four months. Cassini's mission ends in 2017 and JWST will be launched the following year.

•The map below is constructed from images by ESO's VLT, with a resolution of 360 km, just slightly better than JWST's resolution at 2 microns. The superposed line is 2000 km in length, and changes over such scales will be easily seen by JWST.



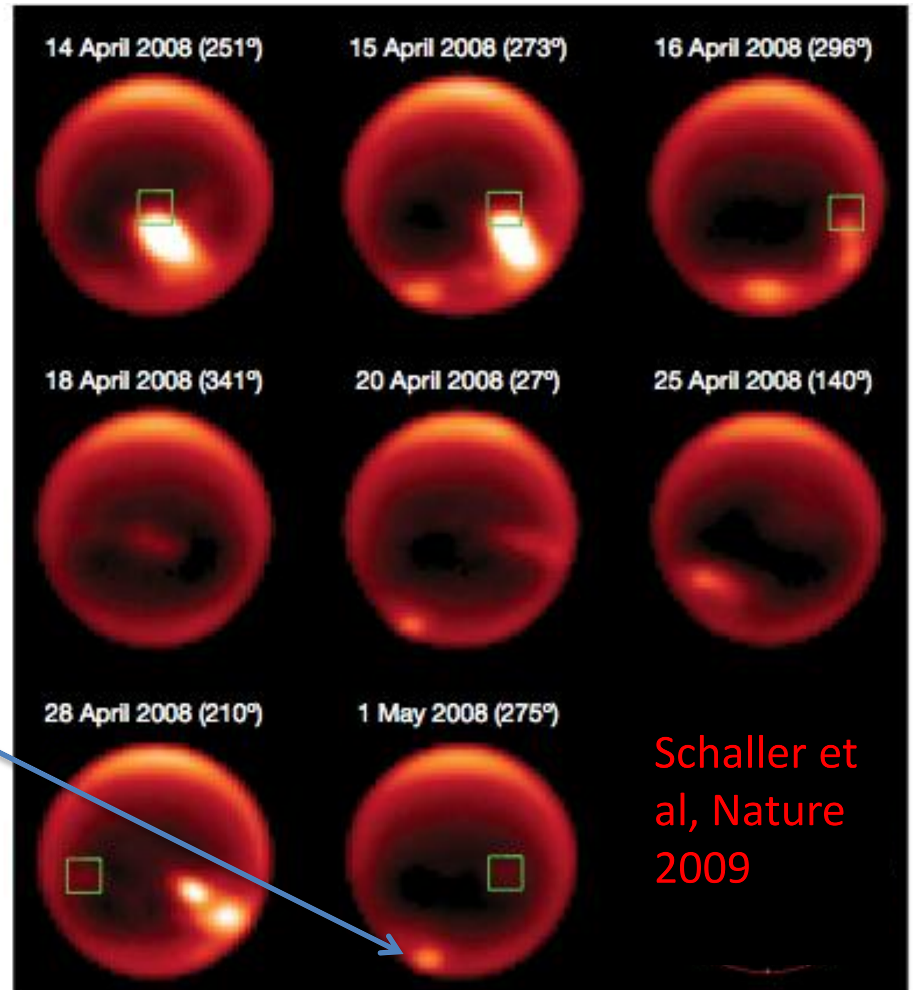
Tracking teleconnections equator to pole

Titan has seasons, just as the Earth does—and with about the same amplitude of tilt. But each Titan season is 7 years long. When JWST is launched it will be early northern summer, and the Cassini Solstice mission will have just ended. This is the time when the north polar region—home to Titan's methane-ethane seas—will be receiving maximum sunlight and reaching their highest temperatures. Cassini has never observed this seasonal phase of Titan.

•JWST can observe over many wavelengths, and hence a wide altitude range, for atmospheric changes including cloud systems that might be triggered by the abundant sunlight in northern summer—the period from 2017-2025.

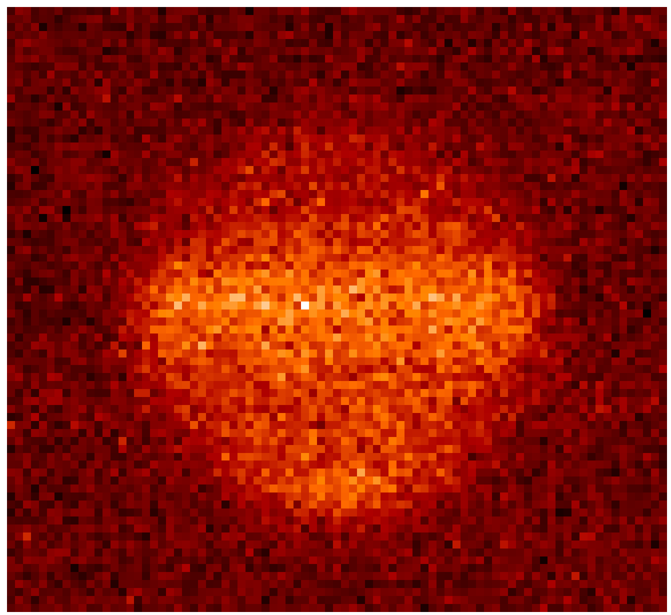
•JWST can map out possible seasonally-driven "climate teleconnections" between the polar and equatorial atmospheres. Such teleconnections have been observed from Earth: Images on the right from Gemini observatory show a large cloud outburst in the equatorial region of Titan, which may have triggered the south polar cloud (arrow) seen some two weeks later.

•Simultaneous measurements with a polar probe (*TiME*) will be of very high value.



Uranus in the mid infrared

2006 September 3
VLT/VISIR 18.7-μm image
G. Orton and colleagues



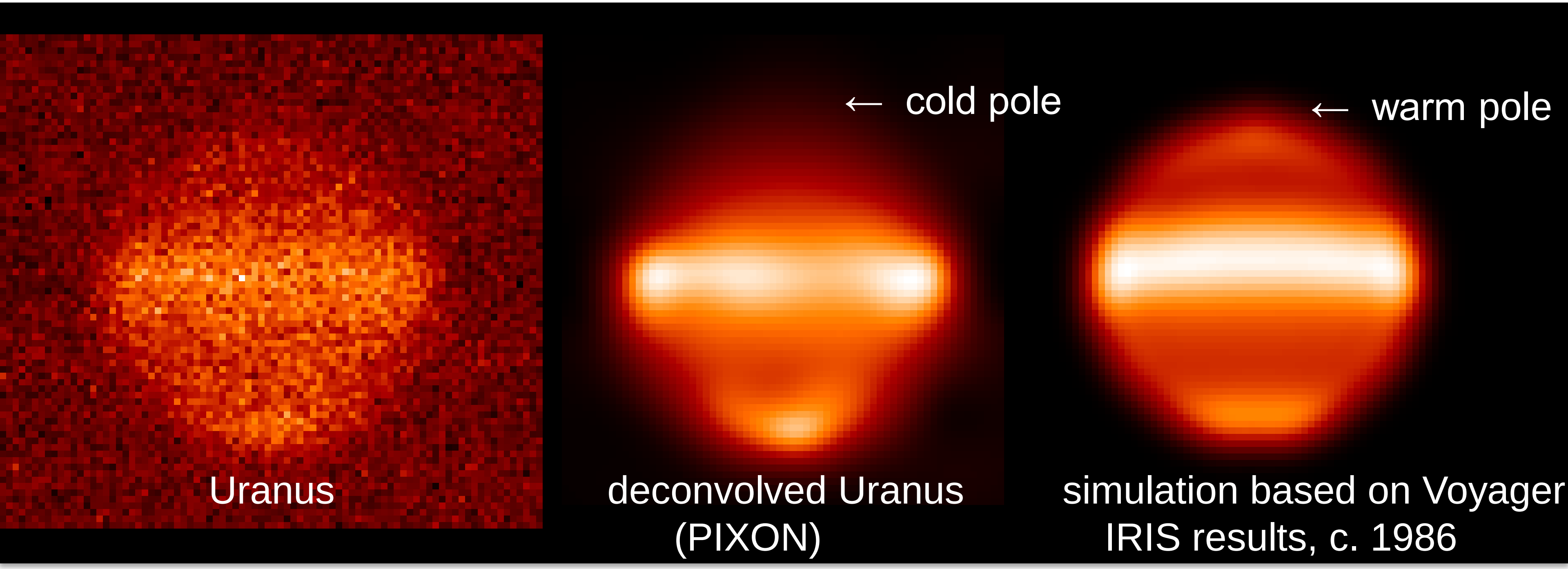
H. Hammel Chart

MIRI resolution

20-year evolution of atmospheric temperatures on Uranus

Comparison with simulated image based on Voyager IRIS T(p,lat.)

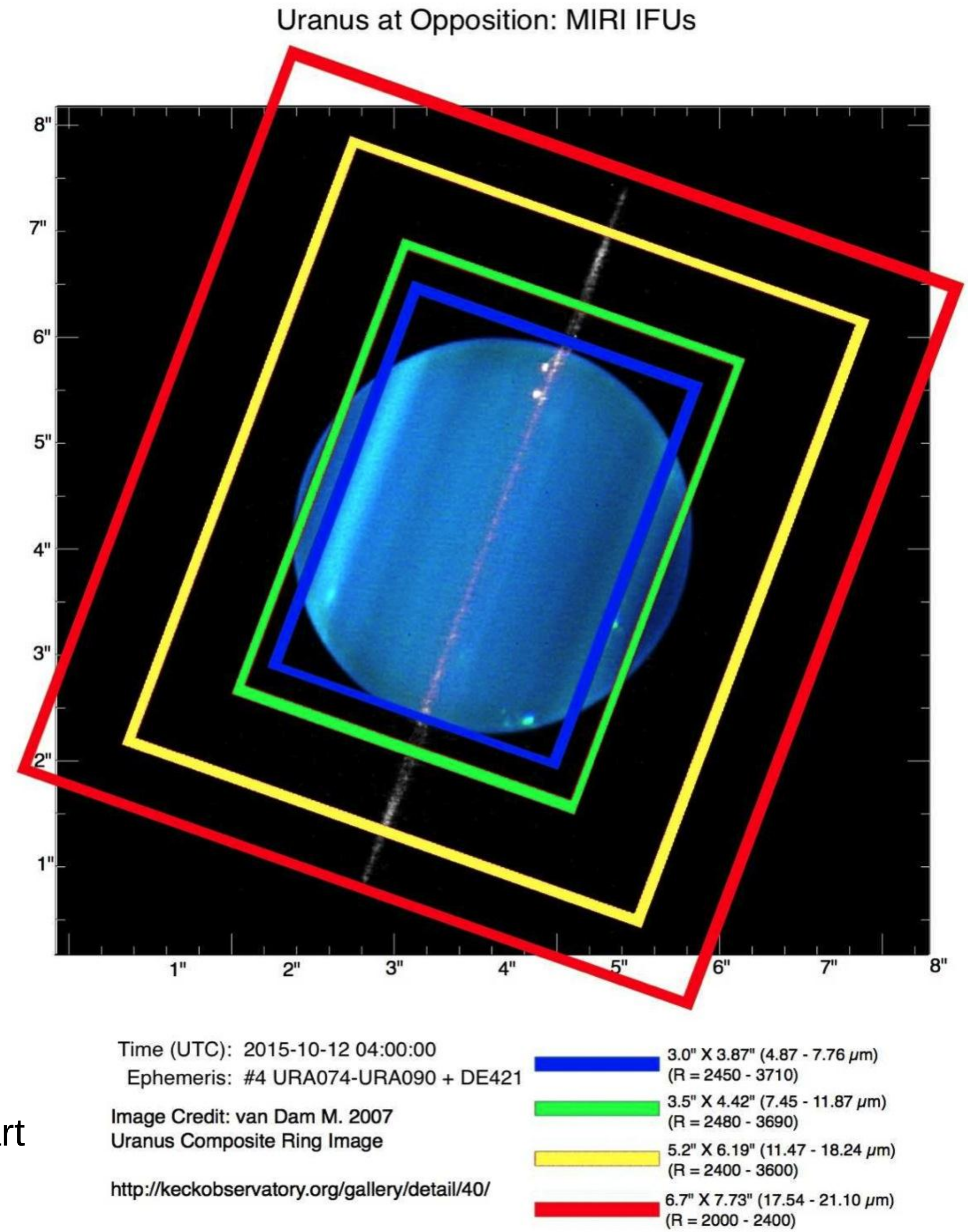
2006 September 3, VLT/VISIR 18.7-μm image



O MIRI resolution

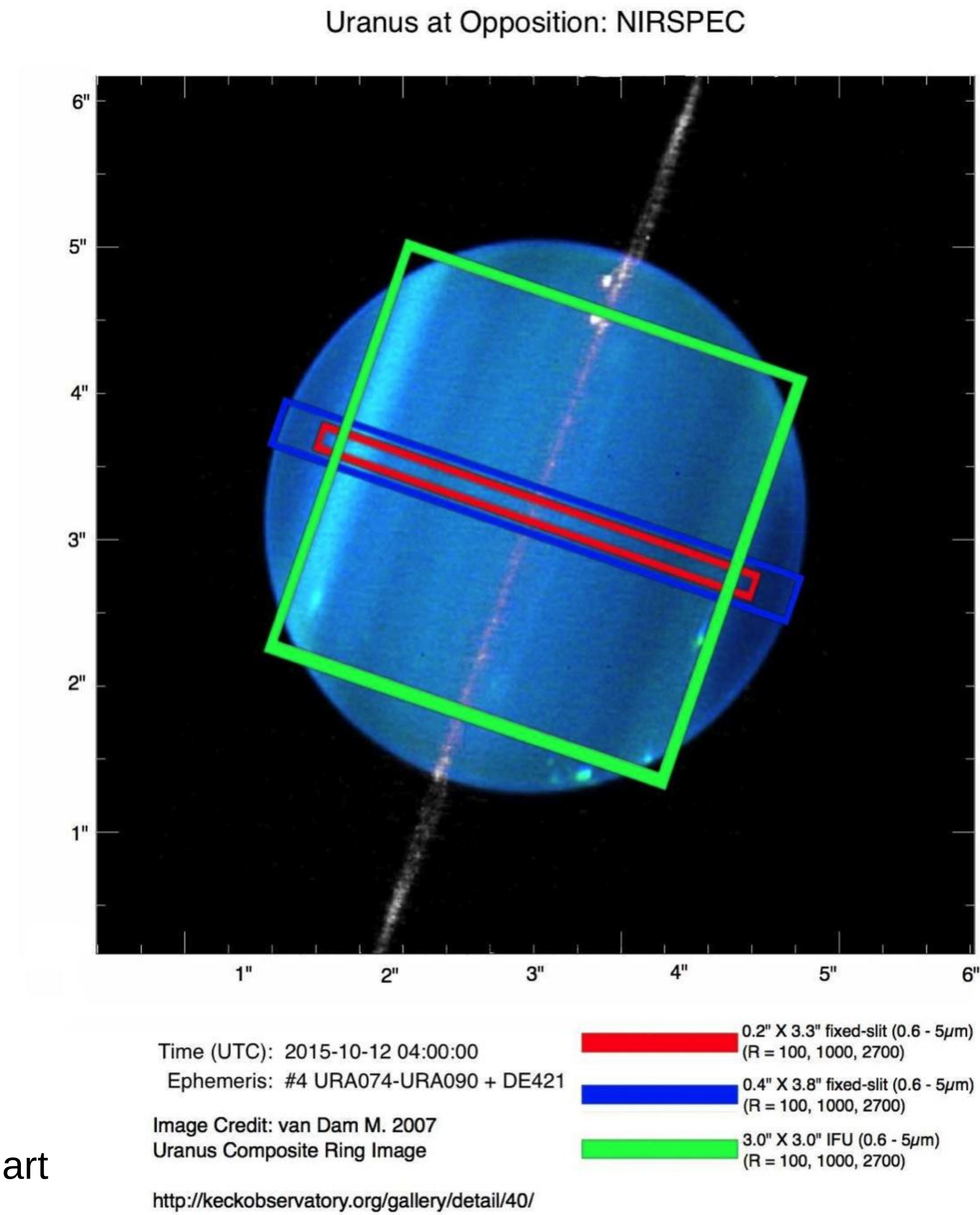
H. Hammel Chart

Uranus with JWST/MIRI IFU: simultaneous, resolved spectroscopy of entire planet



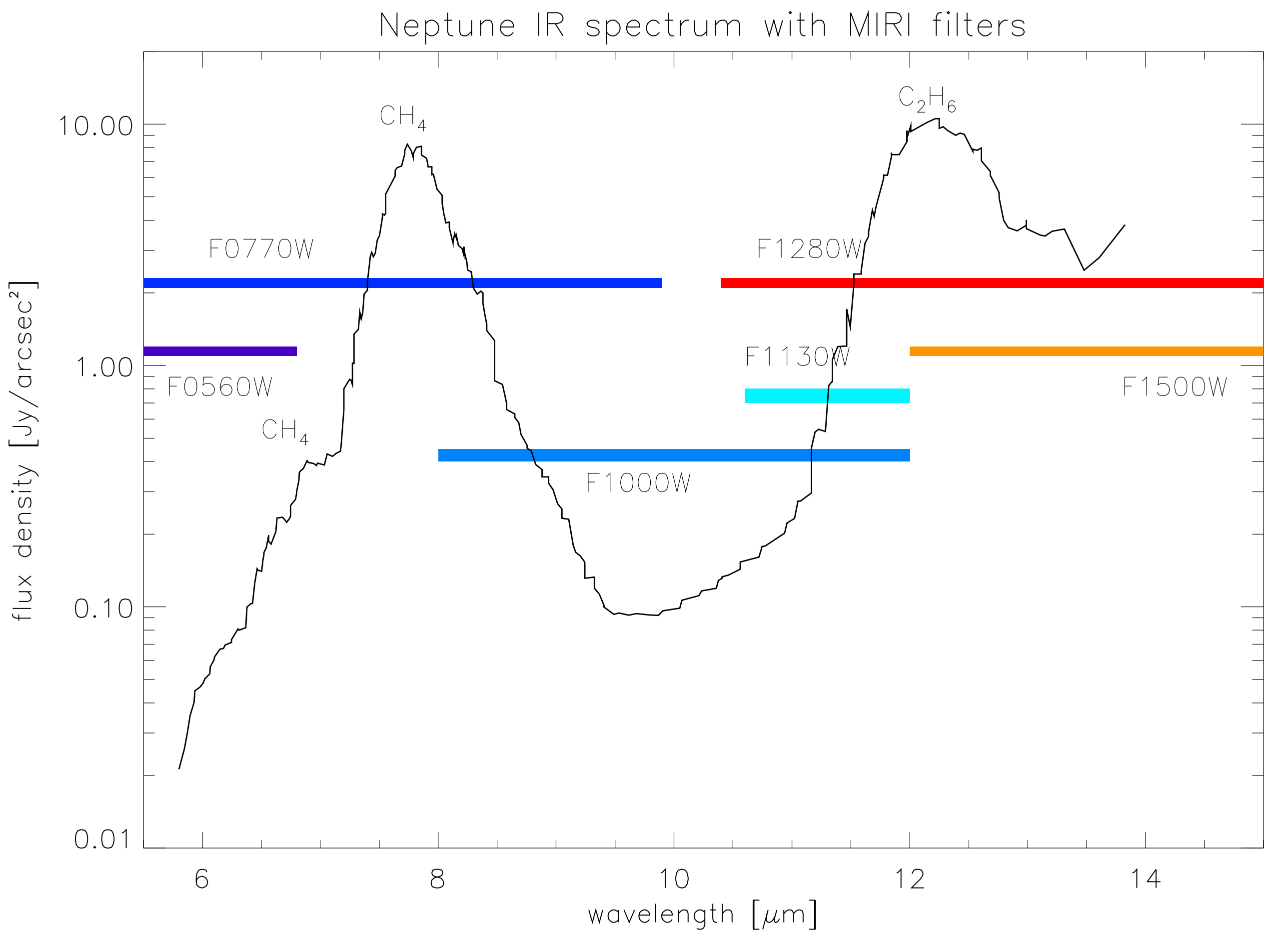
H. Hammel Chart

Uranus with JWST/NIRSPEC fixed slit spectroscopy and IFU



H. Hammel Chart

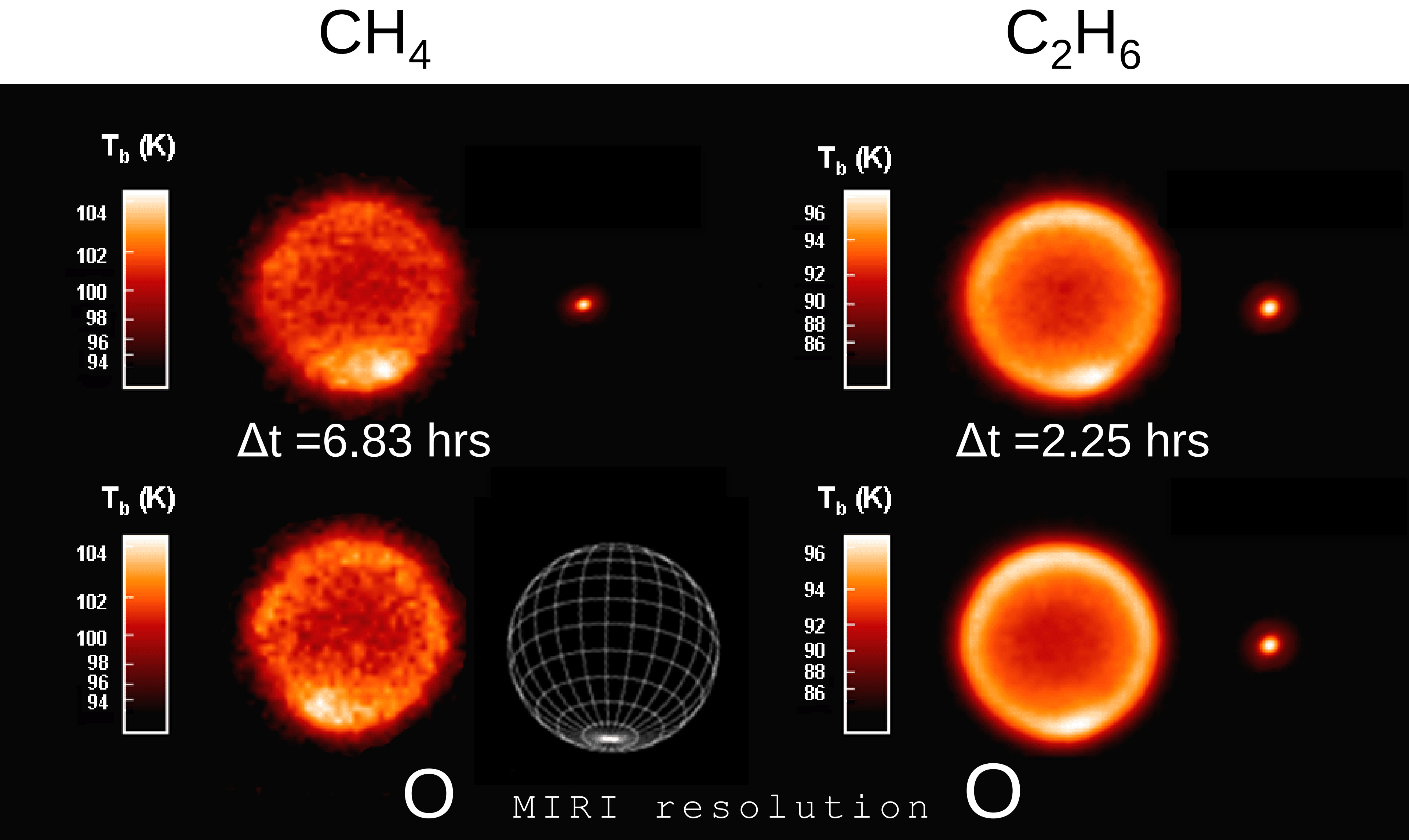
Neptune spectra



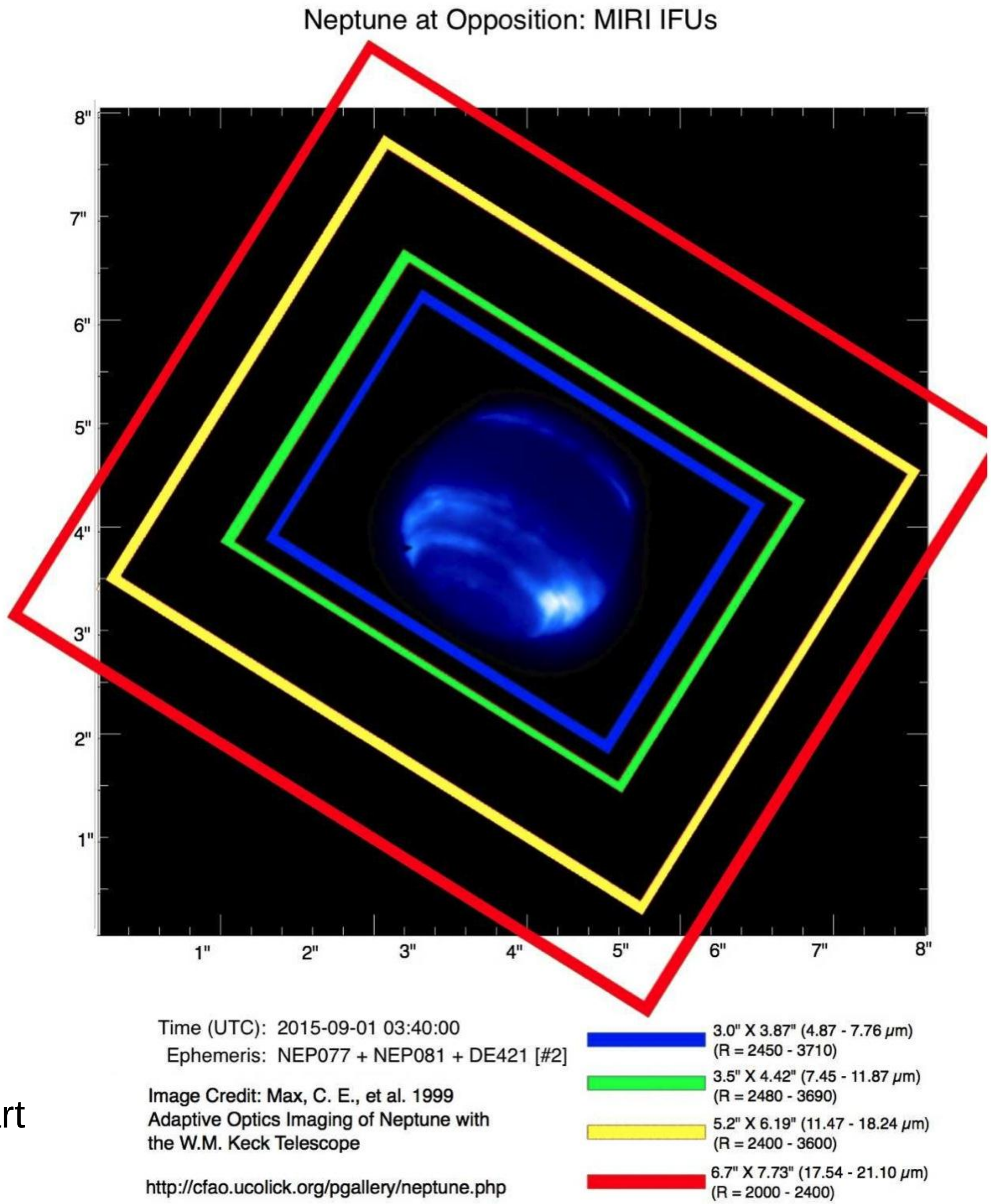
H. Hammel Chart

Neptune's Stratospheric Emission

H. Hammel Chart



Neptune: spatially resolved spectroscopy with JWST/MIRI IFU



H. Hammel Chart

Want to Learn More about JWST?

THE JAMES WEBB SPACE TELESCOPE

Gardner et al. 2006,
Space Science Reviews, 123/4, 485
http://jwst.nasa.gov/scientists.html

2011 Conference
Webcast and Charts
http://webcast.stsci.edu
"Webcast Archives"

White Papers:

- JWST in Decadal Survey
- Solar System Objects
- Dark Energy
- Transiting Planets
- Coronagraphy
- Planetary Systems
- Stellar Pops
- Star Formation
- Galaxy Assembly
- First Light
- Astrobiology
- Scientific Capabilities
- Observatory Planning

Science White Papers
http://www.stsci.edu/jwst/science/whitepapers/

JWST FAQ for Scientists:

Search Strings to learn more:

- "jwst nasa" (≠ Jamaican Water Slide Team)
- "jwst science", "jwst webinar" for online Town Hall,
- "jwst science white papers",
- "jwst ssr" for Space Science Reviews issue,
- "jwst etc" for exposure time calculator,
- "jwst frontiers" for 2011 conference videos and charts,
- "jwst solar system science",
- "jwst apt" for JWST astronomer's proposal tool, in prep

DPS workshop next week!

- Sunday morning, 9 am – 12 noon, Oct. 14
- Tell us what you want JWST to do for you
  - Anything we forgot?
- Start preps for proposals in late 2017
  - Learn specs and capabilities
  - How to start
- If you're coming, write to Stefanie.N.Milam@nasa.gov to make sure we save a spot for you

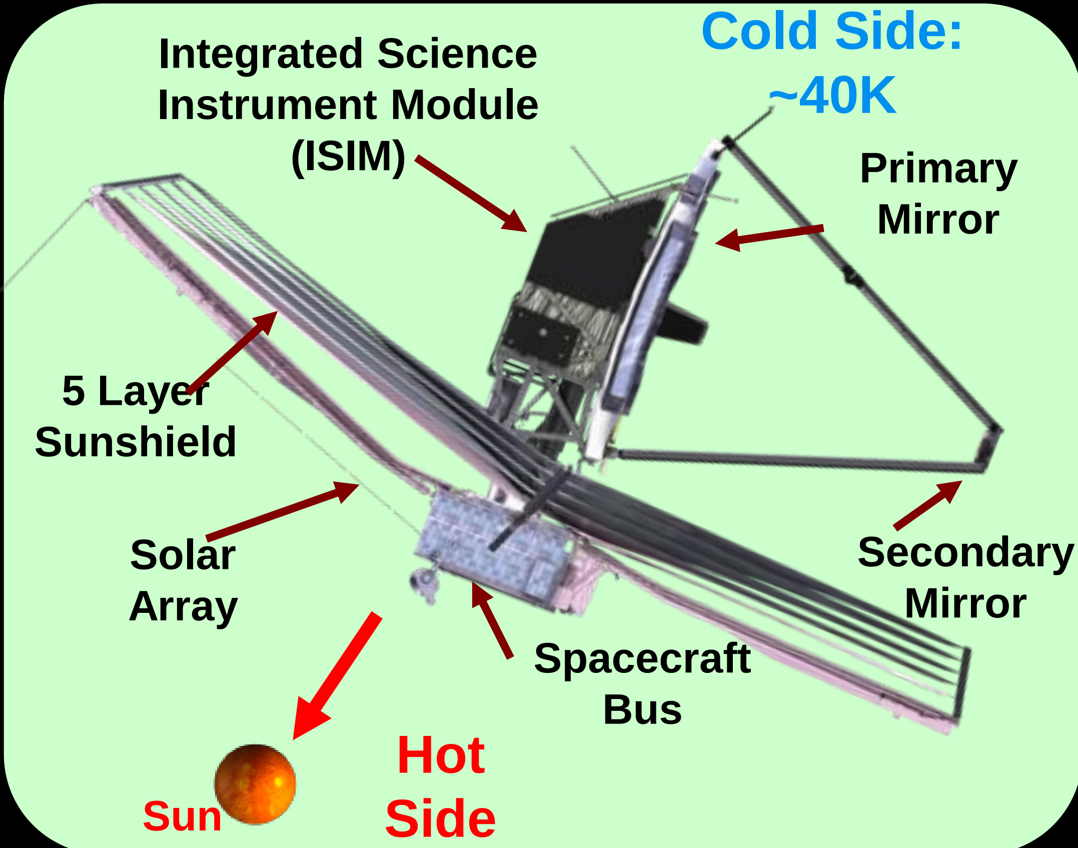
Science Operations Design Reference Mission and Proposal Preparation

- 2012 update: example use case, developed by 50 astronomers, showing 112 possible observing programs across all areas including solar system, exercising and configuring instruments
- Used to test software, including scheduling system, and optimize observing efficiency
- Will be posted soon: search "JWST SODRM"
- Useful reference for proposals!
- First GO proposal call 1 year before launch: 2017

The End

- Questions?

HOW JWST WORKS

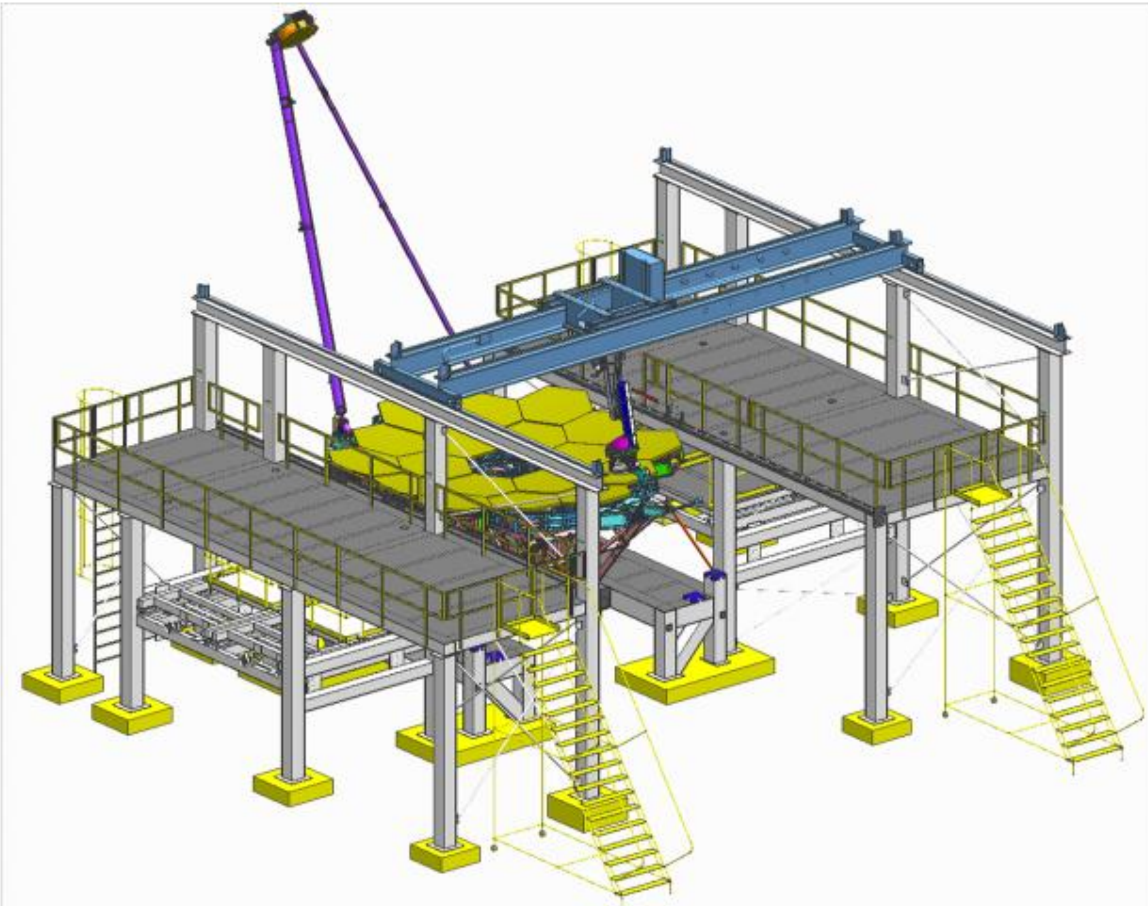


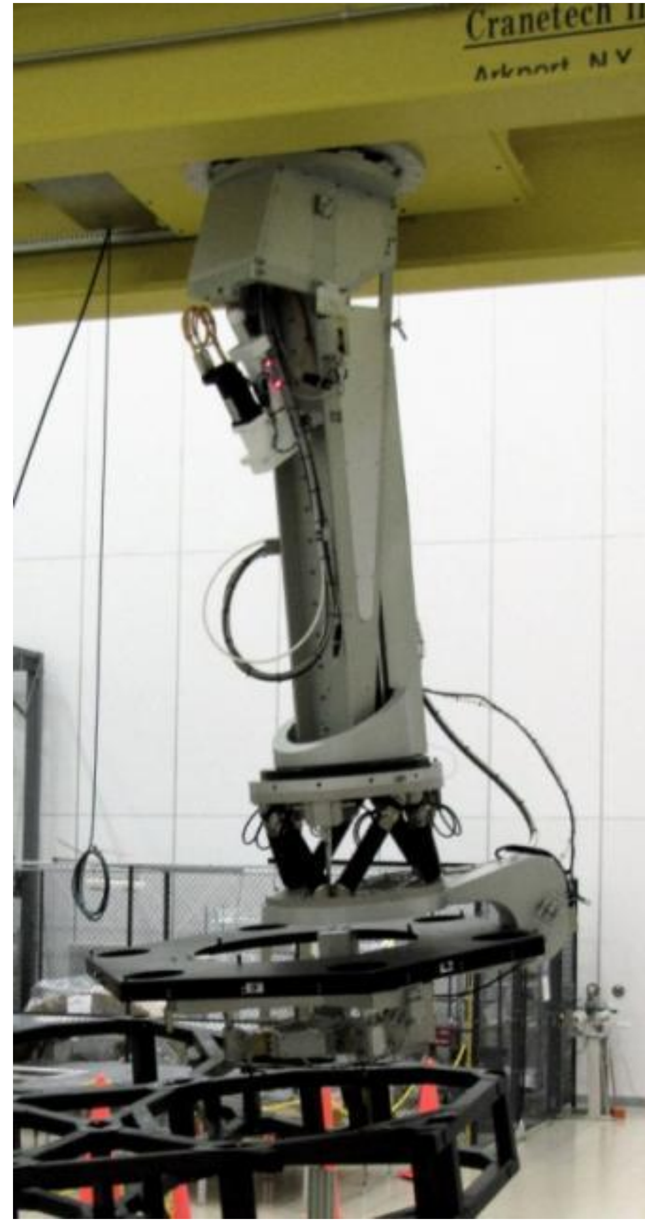
JWST is folded and stowed for launch

Observatory is deployed after launch

JWST Orbits the 2nd Lagrange Point (L2)

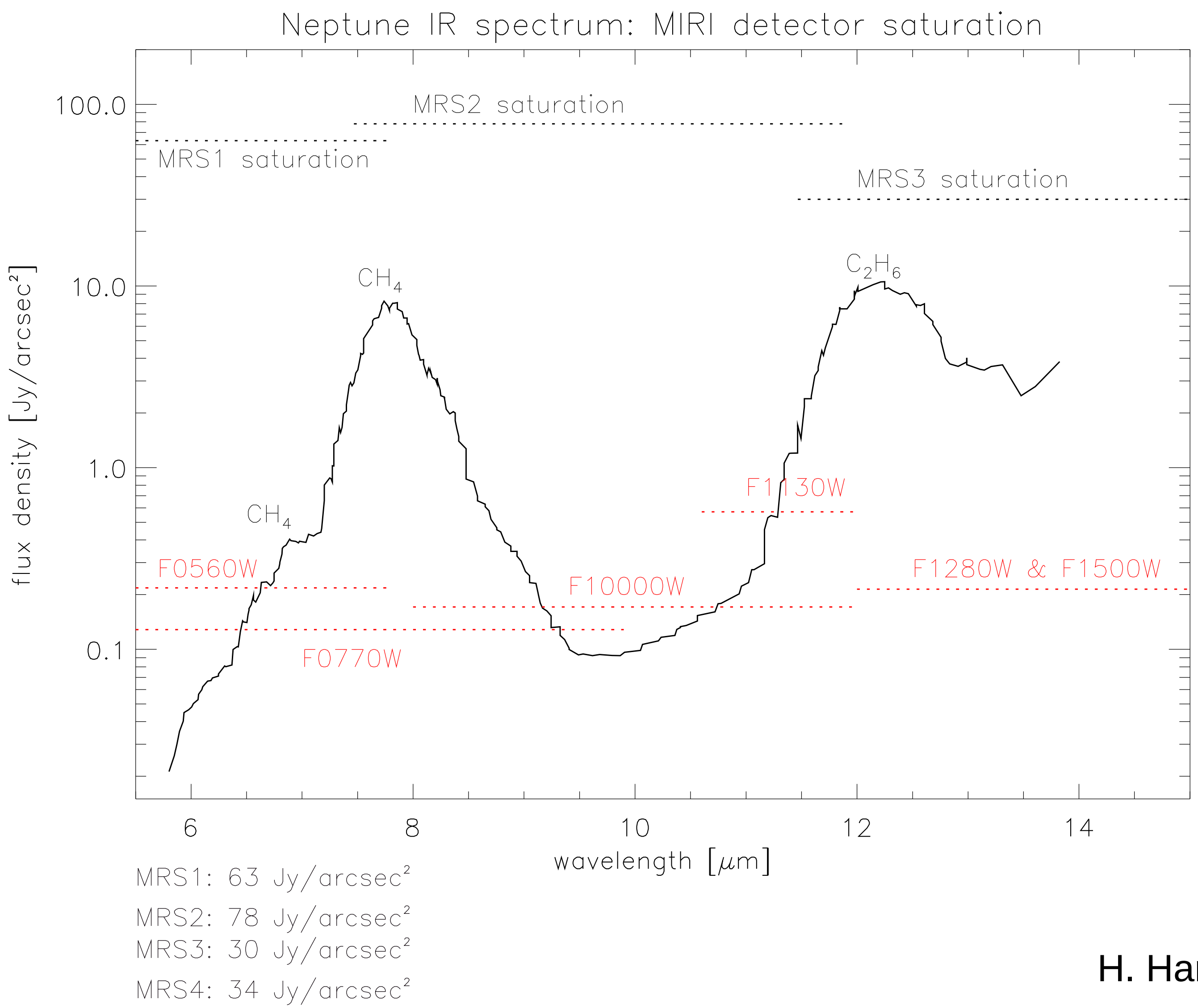
Optical Telescope Element will be integrated on this alignment stand using the machine at right for primary mirror segment installation





followed by attachment of the ISIM to make OTIS – scheduled for 2016

Neptune - too hot to handle?



H. Hammel Chart